

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicants: Zhong Dong et al
Assignee: ProMOS Tech. Inc.
Title: METHOD OF FORMING ONO-TYPE SIDEWALL WITH REDUCED BIRD'S BEAK
Serial No.: 10/821,100 Filing Date: April 7, 2004
Examiner: Vu David Group Art Unit: 2818
Docket No.: M-15295 US Confirmation No.: 8965

Santa Clara, California

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Declaration of Chiliang (Larry) Chen Traversing Grounds of Rejection
Pursuant to 37 C.F.R. §1.132

Dear Sir:

I, Chiliang ("Larry") Chen, declare as follows:

1. My current residence is in Sunnyvale, California.

2. OCCUPATIONAL AND EDUCATIONAL CREDENTIALS

2a. I am currently an employee of Mosel Vitelic Corp. (MVC, Santa Clara, CA facility). MVC is an affiliate of the assignee of the above-identified patent application (ProMos Tech. Inc.). My current position at MVC is Engineering Manager (from 2004 to the present). I previously held the position of Staff Engineer at MVC (2002-2004). In both positions, I was responsible for development of flash memory chips in the 70nm, 0.12 μ m, and 0.18 μ m channel length regimes. This work included overseeing development of HDP-CVD recipes for STI gap-fill to meet isolation requirements; overseeing development of sidewall

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oxidation methods (including ISSG) for use in reduction of Bird's Beak; overseeing development of recipes for nitridizing oxide layers in ONO stacks; and overseeing development of RTP annealing recipes and selection of dielectric capacitor materials for use in mass production fabricating of ONO stacks. A number of the named inventors work with me at MVC in the Northern California research facility.

2b. I personally have approximately 11 years of work related experience in the field of forming dielectric insulating layers in mass-produced integrated circuits, and particularly in the problems of fabricating dielectric layers and reducing or avoiding Bird's Beak. Prior to joining MVC, I worked at Applied Materials (Santa Clara, CA) and held the positions there of Member of Technical Staff (1999-2002), Applications Lab Manager (1997-1999) and Senior Process Engineer (1995-1997). Part of my work at Applied Materials involved development of advanced gate and capacitor dielectric layers by use of ALD-deposited Al_2O_3 , LPCVD-deposited SiN and $SiON$, use of RTO and ISSG. In most of my work-related experiences I have been intimately involved in process related details including formation of silicon oxides and silicon nitrides by various methods including formation of ONO stacks within the context of mass production of IC's.

2c. In 1996 I was awarded a Ph. D. in Chemical Engineering from the University of Minnesota. In 1986 I received a B. S. degree in Chemical Engineering from the National Taiwan University.

2d. I co-authored a number of professional papers including: (a) *Enabling Single-Wafer Process Technologies for Reliable Ultra-thin Gate Dielectrics*, with G. Miner, G. Xing, S. J. Hyun, E. Sanchez, Y. Yokota, D. Lopes, A. Balakrishna; Electrochem. Soc. Symp. Proc. 99-10, 3 (1999); and (b) *Attainment of Low Resistivity Polycide Films Using Rapid*

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Thermal Annealing, with H. A. Yoon, A. Singhal, D. Lopes, G. Miner, S. Hong, Y. Maeda, M. Yamazaki, Electrochem. Soc. Symp. Proc. 99-10, 249 (1999).

2e. I am a named co-inventor on the following US patent: 6,066,836 issued May 23, 2000 and entitled: *High temperature resistive heater for a process chamber*. I am a named co-inventor on the following US patent applications: 2002/0168840 published November 14, 2002 and entitled: *Deposition of tungsten silicide films*; and 2003/0000647 published January 2, 2003 and entitled: *Substrate processing chamber*.

2f. My professional work experience and educational background make me well qualified to opine on the understandings of persons of ordinary skill in the relevant art and at the relevant times as detailed below.

3. DOCUMENTS REVIEWED

3a. In preparing for making this Declaration, I reviewed the following documents:

3.1) Originally filed patent application Ser. No. 10/821,100, filed 4/7/2004 by Zhong ("Mark") Dong et. al (hereafter also "the subject patent application");

3.2) Final Office Action (OA) of June 6, 2006 for said Ser. No. 10/821,100 and the subsequent Advisory Action of August 21, 2006;

3.3) Applicant's Response After Final August 2, 2006 of for Ser. No. 10/821,100;

3.4) You U.S. Pat. 6,706,613;

3.5) Wang U.S. Pub. 2005/0110102 (published 5/26/05 on basis of application filed 11/25/03); and

3.6) Xing U.S. Pub. 2003/0124873 (published 7/3/03).

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4. REVIEW OF FINAL OFFICE ACTION

4a. As I am given to understand, in the Final Office Action (OA) of June 6, 2006, as well as in the Advisory Action of August 21, 2006, the examining official (hereafter "Examiner") at the U.S. Patent and Trademark Office (hereafter "PTO") asserted either expressly or by implication that a person of ordinary skill in the art at a time prior to April 7, 2004 (hereafter "critical date") would have been motivated and enabled by the teachings of You '613 in combination with other prior art teachings that demonstrate use of ISSG (e.g., Wang '102) to use a particularly dry form of ISSG (In Situ Steam Generation) for forming sidewall oxide on an ONO stack (Oxide/Nitride/Oxide dielectric stack) such as stack structure 120 of You Fig. 2B. In doing so, the ordinary artisan would reduce Bird's Beak formation, namely the oxide encroachment shown in Region "A" of You Fig. 1 between the polysilicon control gate 18 and the polysilicon floating gate 14. The Examiner appears to assert that a person of ordinary skill in the art at a time prior to the critical date would have been motivated to reduce Bird's Beak in this way because You '613 teaches to reduce Bird's Beak; and further that such an ordinary artisan would have been motivated to use a relatively dry formulation of ISSG (such as within the low end of the ranges stated in Wang '102) in place of the "dry oxidation" taught by You '613 at col. 6, lines 38-40. The motivation for using the relatively dry formulation of ISSG instead of You's fully dry thermal oxidation is stated in the Final Office Action as, because "a dry ISSG process provides excellent thickness control and the thermal budget can be reduced" (OA page 3, last 5 lines of first full paragraph, emphasis added). This was the general basis, as I understand it, for rejecting the then pending claims as being "obvious".

4b. It is to be understood that I am not opining here about the legal "patentability" of any claims, as amended or otherwise formed, and which the Applicant may be presenting

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concurrently or in the future to the PTO. I am not opining about whether the legal scope of any claim includes limitations of its "preamble" (introductory paragraph) or not. My role here is that of reviewing the documents from a technical perspective and reviewing the fact-finding conclusions reached by the PTO and not the ultimate legal conclusions. As such, I will not be opining on what would have been legally "obvious" to one of ordinary skill in the art prior to the critical date. Instead I am opining, based on my education, background, and review of the above-stated materials, regarding what an ordinary artisan (at or before the critical date) would have understood from the applied prior art documents, from general knowledge in the art, and what an ordinary artisan would have been motivated to do or not do in light of such documents but without having hindsight knowledge of the invention set forth in the subject patent application.

4c. Let me begin by providing some important, detailed information about metal silicides and ISSG. It is to be noted that You '613 has a metal silicide layer (111 in Fig. 2A and 112 in Fig. 2B) as part of his ONO stack in a step prior to when sidewall oxidation begins. Then, at column 6, lines 38-40, You cautions that the oxidation should be a "dry" one. This term, "dry" indicates to the skilled artisan that there should be essentially no hydrogen in the oxidation atmosphere.

4d. There is a very good reason for why You '613 insists on a "dry" oxidation. It is not a user-bypassable option. Hydrogen tends to act as a catalyst for encouraging decomposition of metal silicides. At oxidation temperatures, the decomposition reaction: $\text{Si-M} \rightarrow \text{Si} + \text{Metal}$ will be accelerated by the presence of hydrogen. Then the oxygen in the atmosphere will oxidize the silicon and metal byproducts of the decomposition to produce electrically insulative oxides. As a result, the metal silicide layer (112 in You Fig. 2B) will be quickly covered by insulation and it will cease to function in its desired role as a metal gate contact (to

poly 109). Thus this constitutes one reason for why an ordinary artisan would heed the directions of You '613 and would avoid using a thermal oxidation process that includes hydrogen. In other words, because an ISSG atmosphere includes hydrogen, the ordinary artisan would see You '613 as teaching away from use of ISSG.

4e. With that first point out of the way, I wish to return to the Patent Office's reasoning as quoted and highlighted in above paragraph 4a (namely, that the motivation to use dry ISSG is because "a dry ISSG process provides excellent thickness control and the thermal budget can be reduced" (OA page 3, referring to Wang Abstract, emphasis added). In my professional opinion this statement is technically incorrect and without basis in Wang '102. Wang never promises or suggests that a "dry" version of his ISSG process will provide excellent thickness control for every situation. Moreover, a "dry" ISSG that does not have enough hydrogen flow to sustain a stable hydrogen flame will tend to increase consumption of the thermal budget rather than decreasing it. (This is so because the hydrogen flame provides localized exothermic heat, and without the flame, a non-local source of heat will probably have to be used (i.e., Rapid Thermal Heating lamps) and this will tend to hurt rather than help the thermal budget of the overall chip. More on this detail later.) With regard to universal applicability of ISSG to all situations, Wang's Abstract limits itself to saying: "Exposing the patterned silicon nitride to the oxygen radical during the RTO according to the invention significantly reduces the processing time, and reduces the thermal budget." Wang does not teach or suggest a universal applicability of his method. I could not find any instance where Wang mentions the word "excellent" or associates the "dry" end of his ranges with good thickness control or thermal budget reduction. The only instance of "control" that I found in Wang is at paragraph [0048] where he says: "Formation of thin oxide films on nitride using conventional methods follows a linear growth law. In contrast, formation of oxide [on nitride]

by ISSG is apparently diffusion controlled, as the square of oxide thickness values[,] is linearly proportional to oxidation time, and it conforms to the parabolic growth law." [Bracketed language and emphasis added]. From this, an ordinary artisan would see Wang '102 as being focused on how to form oxide (SiO) on silicon nitride (SiN). He would not see Wang '102 as suggesting that ISSG can be (or should be) used in every situation where excellent thickness control is to be maintained. As I already explained above, ISSG cannot be arbitrarily used in every arbitrary situation. If a metal silicide is present for example, the ordinary artisan should be highly motivated to not use an oxidation process that exposes the silicide to hydrogen. The ONO stack structure of You '613 constitutes such a situation. Thus, the ordinary artisan would have no motivation for combining You '613 and Wang '102.

4f. Now that I have provided some detailed technical observations regarding metal silicides and dry versus hydrogen-laden oxidation, this may be a good place in the discussion for stepping back to review some basics regarding the formation of Bird's Beak. I think this review will help to better position the teachings of You '613 relative to the context of Bird's Beak and also to show why the subject patent application discloses a method which is substantially different from that of You '613 and which is not suggested by Wang '102 either.

4g. It is well known in the art of semiconductor fabrication that oxygen molecules (O₂) can readily diffuse through conventional silicon dioxide (typically, amorphous SiO₂). In other words, silicon dioxide appears as being a relatively porous material to conventional, thermal oxidation processes. This is generally a desirable trait because it allows a thermal oxidation front to reach through to new silicon after oxide has already grown over previously exposed silicon. It is the easy permeation of high temperature oxygen through porous silicon oxide which makes the general process of thermal oxidation not only possible, but relatively fast and cost efficient in terms of energy expended for achieving the desired end result.

4h. The oxide-permeating (penetrating) property of oxygen during thermal oxidation becomes a problem however in situations such as that of Fig. 2A of You '613 where one or more silicon oxide layers (105 and 107) lie immediately adjacent to a silicon layer (i.e., the floating gate (FG) polysilicon 103 and the control gate (CG) poly 109 of You '613) and the oxide layer is "exposed" to the oxidation atmosphere. In such a case, the porosity of oxide layers 105, 107 allows energized oxygen to permeate laterally into the stack. As the permeating oxygen reaches the outer corners of the upper major surface of FG layer 105 and also the outer corners of the lower major surface of CG layer 109, it reacts with silicon in the corners and converts them into enlarged volumes of silicon dioxide. Volume enlargement is one of the well known attributes of thermal oxidation. This can lead to undesired mechanical strain as well as undesired alteration of geometries for the dielectric and the conductive layers around it. The undesirable outcome of corner erosion and increased strain is indicated to have occurred in region "A" of You Fig. 2. It is seen that the upper corners of FG layer 14 have been consumed and converted to oxide due to lateral oxygen permeation through ONO structure 16. The lower corners of CG layer 18 have also been consumed and converted to oxide by virtue of such lateral permeation of oxygen through the porous oxide layers of the ONO structure 16. While not shown; it is understood that the dielectric material between poly gates 14 and 18 has been strained by the undesired lateral growth of oxide. This undesirable intrusion of an enlarged-volume of oxide into a critical region of capacitive coupling is often referred to by practitioners as "Bird's Beak". It is undesirable because it alters the electrical behavior of the dielectric and of the conductors (usually polysilicon) that sandwich the interposed dielectric. The Bird's Beak problem is a notoriously old one. There has been a long felt need in the industry to come up with economic and consistent ways of preventing or reducing Bird's Beak. Numerous techniques have been tried with varying degrees of success.

Each approach has its positive aspects and its drawbacks, particularly when practiced on a mass production line. Consistency of outcome is important during mass production.

4i. The degree to which Bird's Beak forms is dependent on numerous process specifics including but not limited to: (1) What is the crystalline structure of the oxide layer (i.e., highly amorphous or not?) through which the oxidizing agent will be permeating laterally? (2) What is the rate of permeation of the oxidizing agent? (3) What is the composition of the adjacent silicon (i.e., polycrystalline, monocrystalline, amorphous)? (4) What is the rate of oxidation of the adjacent silicon by the given oxidizing agent at the given process temperatures, pressures and reactant flow rates? Given all these variables, it is difficult for an ordinary artisan to anticipate ahead of time, and without significant experimental experience how Bird's Beak will develop under an unfamiliar type of oxidation. Silane-based (or dichlorosilane-based) HTO oxidation has been the oxidation method of choice in the industry for ONO sidewalls. The reasons why are detailed later below. As such, a significant body of experimental data already exists for how Bird's Beak forms under the specific conditions of various silane-based HTO recipes. Also, a significant body of experimental data already exists for how Bird's Beak forms under the specific conditions of older, dry oxidation methods. To the best of my knowledge and belief, very little industry-wide data was available prior to the critical date for how Bird's Beak might form under the specific conditions of various ISSG recipes. A person of ordinary skill in the art would not see ISSG as an obvious-to-try method for oxidizing ONO sidewall because the outcome is unknown without resort to undue experimentation. By contrast, the outcome for the industry-conventional silane-based HTO recipes or dry oxidation recipes is much better understood. So the person of ordinary skill would have been motivated (prior to learning of the excellent results obtained by the subject patent application) to shy away from ISSG or other forms of

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nonstandard sidewall oxidation and to stick with the tried and true conventional methods, namely, silane-based HTO recipes. This is another reason why a person of ordinary skill would not view the teachings of You '613 as an invitation try all forms of alternate oxidations aside from the dry oxidation which You '613 has apparently already validated as providing good Bird's Beak results. It is not at all clear how ISSG or other forms of oxidation might fair (in terms of forming Bird's Beak or not and providing sufficient rate of sidewall oxidation) under the conditions of the ONO structure of You '613 where a nitride barrier covers the exterior of the ONO stack and impedes the advancement of the oxidizing agent.

4j. This is a good point to discuss the nitride coating which You '613 forms in his "pre-anneal" step of col. 6, lines 8-37. Just as it is known in the art that oxygen can diffuse easily through silicon dioxide, it is also well known that oxygen has a difficult time of diffusing through silicon nitride when conventional thermal oxidation techniques are used. Silicon nitride (stoichiometric Si_3N_4 or other compounds of silicon where many S-N bonds are formed) is often used as an "oxidation stop" or an "oxidation barrier" because of this phenomenon. It is used to stop or substantially slow the progress of an advancing oxidation front during a thermal oxidation process.

4k. In fact, prior to the critical date, it would have been very clear to an artisan of ordinary skill that You '613 teaches at col. 6, lines 8-37 to use silicon nitride as a thin diffusion barrier on the sidewall of an ONO stack for precisely this purpose; for slowing down lateral permeation of oxygen into the interior of the stack during thermal oxidation of the sidewalls of his FG/ONO/CG stack 120 of Fig. 2B. You '613 implicitly teaches at col. 6, lines 36-37 that, were it not for the S-N bonds formed in his nitrogen pre-anneal step of col. 6, lines 8-25, that "oxidizing agents" would have "penetrate[d]" into the central portion of the ONO layer 108 [in other words, deep into region "A" of You Fig. 1, reaching as far as the outer

boundary of region "B"]" [*Bracketed text added*]. You '613 unequivocally teaches at col. 6, lines 29-35 that a film containing strong silicon-nitrogen bonds (S-N bonds) should be formed on the sidewall 102a of stack 120 before the stack is subjected to the thermal oxidation (to the "dry oxidation" of col. 6, lines 38-40). The pre-oxidation anneal in the nitrogen containing atmosphere causes the sidewalls in You's stacked gate structure 120 to be covered and protected by a thin nitride film such that they are not directly exposed to the thermal oxidation environment. In other words, You's stacked gate structure 120 does not have openly exposed oxide to serve as a gateway through which oxygen can readily enter laterally into the interior of the ONO structure to thereby quickly begin the process of Bird's Beak intrusion. You's ONO structure is covered on its sidewall with nitride before thermal "dry oxidation" is initiated at col. 6, lines 38-40. This aspect of You '613 is not ambiguous or open to reasonable debate. Instead, it is the whole basis of the invention described by You '613. You uses the thin nitride coating to slow down entry of laterally permeating oxygen into the regions between his FG and CG layers, and to thereby reduce the Bird's Beak incursion as is shown in region "C" of You Fig. 2C. Note that the amount of lateral incursion by material 116 of You Fig. 2C into the interior of the stack is substantially less than lateral incursion by material 26 of You Fig. 1.

4l. Given the above, it is my opinion based on my experience and educational background that a person of ordinary skill in the art, at or before the critical date, would have understood You '613 to be clearly teaching the following:

- Do not leave an open or exposed silicon oxide surface on the sidewall of the ONO stack structure as you are about to begin thermal oxidation, but instead cover all such entrances or gateways for lateral permeation of oxygen with an oxygen diffusion barrier such as silicon nitride; and

- Use a dry oxidation with O₂ (no hydrogen in the oxidizing atmosphere) for simultaneously oxidizing the nitride-covered sidewalls and for annealing lateral ends of the ONO structure so as to thereby relieve any mechanical stress induced by the limited amount of Bird's Beak incursion (region "C" of You Fig. 2C) that does occur.

4m. It is further my opinion based on the above that a person of ordinary skill in the art, at or before the critical date, and upon reading You '613, would have been guided away from:

- Leaving an open or exposed silicon oxide surface on the sidewall of the ONO stack structure when beginning thermal oxidation so as to thereby provide an entryway for lateral permeation of conventional oxidizing agents into the ONO structure; and
- Using a non-dry oxidation process (i.e., ISSG, wet oxidation) for oxidizing the nitride-covered sidewalls and for simultaneously annealing lateral ends of the ONO structure.

As explained above, hydrogen tends to accelerate silicide decomposition. Since You's ONO stack includes a metal silicide layer prior to commencement of the thermal oxidation, a person skilled in the art would be strongly motivated to pay heed to You's requirement for a "dry" oxidation and such an ordinary artisan would not think of instead using an oxidation process that exposes the metal silicide to hydrogen. Moreover, since it is not clear how Bird's Beak formation would proceed if a method other than dry oxidation were tried in the situation presented by You '613, an ordinary artisan would be motivated away from randomly trying alternate methods of sidewall oxidation. Accordingly, You '613 guides the ordinary artisan

away from contemplating the use of ISSG or other non-dry, thermal oxidation processes. Even if for sake of argument, You '613 might be seen as suggesting a try of wet oxidation (see col. 2, line 16 where You '613 mentions wet oxidation (H_2O) as part of the general method for oxidizing exposed silicon), that alone does not recommend ISSG, and more specifically dry ISSG as an alternate method to be tried. In other words, You '613 nowhere recommends that dry ISSG be specifically tried as a method for reducing Bird's Beak and Wang '102 nowhere recommends that dry ISSG be specifically tried as a method for reducing Bird's Beak.

Thermal Oxidation Processes are Not All the Same and Equivalently Interchangeable

5a. The specification of the subject patent application indicates that the ONO sidewall is conventionally oxidized with a silane-based HTO process (High Temperature Oxidation) and that Birds' Beak results. See for example paragraph [0039]: "Another problem with the conventional oxidation processes (e.g., HTO) is that the heated molecular oxidizing agents (e.g., O_2) readily diffuse through the SiO layers ... to thereby attack the underside of Poly ... A set of Bird's Beak formations ... develop as a result of incursion of the molecular oxidizing agents (e.g., O_2) through the SiO layers 114, 116." *[Some detailed text clipped out here.]*

5b. What the specification perhaps leaves out is a detailed explanation of what motivates the ordinary artisan to conventionally rely on a relatively water-free, High Temperature Oxidation (HTO) process such as the exothermic $DCS+N_2O$ reaction described in the specification as opposed to other possible methods of forming sidewall oxide. Not all forms of creating oxide are the same. A person of ordinary skill in the art would not arbitrarily substitute one for the other or pick arbitrary operating parameters for any specific approach.

As I already explained, a hydrogen-free atmosphere should be used when a metal silicide contact layer has already been formed as part of the stack. Careful attention to Fig. 3A of the subject patent application will show that the Poly-2 layer (318) is not yet covered by a metal contact layer, but instead has a silicon nitride pad layer (319) above it as the ISSG sidewall-oxidizing process (320) is initiated. The specification does not highlight these subtleties. However, at paragraph [0061] it indicates that "the pad silicon nitride 319" will generally still be present at the time of the supplemental HTO oxidation 380 and that it will be stripped off by HF etch or otherwise after that."

5c. While it does not provide every minutiae of detail, to its credit, the specification of the subject patent application does explain at specification paragraph [0040] one further aspect that would de-motivate an ordinary artisan from using a dry ISSG, to wit:

[0040] Conventional oxidation for producing sidewall dielectric is not limited to HTO (High Temperature Oxidation). Other conventional methods that have been used include thermal oxidation with **dry O₂** (molecular oxygen) and thermal oxidation with a **wet combination** of O₂ and H₂ (molecular hydrogen) and thermal oxidation **with water vapor** (H₂O). As used herein, the so-called, thermal oxidation with a wet combination of O₂ and H₂ refers to a process where a supplied stream of H₂ is burned (made to produce an invisible flame) in the presence of flowing O₂ to thereby form high temperature water vapor (H₂O) where the volumetric flow ratio of H₂/O₂ (each in terms of sccm) is in the range of 1.0 to 1.8. It is outside of conventional, mass-production practice to reduce the H₂/O₂ volumetric flow ratio below this range (more specifically, below 0.3) because the flame may become unstable at lower values of the ratio. [Emphasis added.]

5c. The reasons why the ordinary artisan would usually want to assure a consistent ignition of the hydrogen flame immediately adjacent to the surface undergoing oxidation are many fold. Xing '873 was used by the Examiner as a source of alleged evidence regarding

radical lifetime (and I will address that issue later). Here I point to Xing paragraph [0039] as showing that the ordinary artisan will conventionally wish to "ignite" the gas containing the oxygen and hydrogen and that the ordinary artisan will conventionally want the surface that is undergoing oxidation is to serve as the "ignition source". This localized ignition of the hydrogen and oxygen sources provides selective application of exothermically-generated heat to just the right places and assures that a large number of oxygen radicals will be present at those places. Thus it is against conventional thinking to try an ISSG recipe where the volumetric flow ratio of H_2/O_2 (each in terms of sccm) is in a range below 1.0 (below unity). The reasons why are detailed immediately below.

5d. Semiconductor fabrication can consume large amounts of energy and process steps can take significant time. It is highly desirable to not waste energy by uselessly heating parts of the wafer that do not need to be heated, especially if this is going to eat into their thermal budgets. It is highly desirable to not waste time by using a process that is relatively slow and fails to provide an adequate supply of oxygen radicals to the place where they are desired. It is also highly desirable to assure consistent results during mass production. In view of this, the person of ordinary skill would want to avoid a non-exothermic ISSG process where there may not be sufficient H_2 flow to assure a consistent and stable hydrogen flame and to thus assure consistent production of exothermic heat generation at the sidewall surface. Note that Xing '873 recommends approximately 10% H_2 at paragraph [0033]. Note that working Example 3 of Wang '102 is a relatively wet formulation where at paragraph [0047] of Wang the disclosed ISSG process has an H_2/H_2+O_2 ratio of about 33% and it is being used to produce a reduced thickness disparity: roughly 0.75 to 1.0 (SiN/Si oxidations) where such a reduced disparity is Wang's goal. Wang '102 cautions that "the ISSG process depends upon

using process pressure, flow rate and temperature in the chamber within specified ranges. ...
[I]n some embodiments the following parameters can be effective: temperature in the range about 800° C to about 1000° C; pressure in the range about 1 torr to about 20 torr; flow rate of H₂+O₂ in the range about 1 slm to about 40 slm. The ratio of H₂/H₂+O₂ is in the range about 0.1% to about 40%. " (at [0032] *Emphasis and bracketed text added.*) Xing '873 also explains at paragraph [0025] that pressure is important and Xing '873 recommends low pressure for the purpose of lengthening the lifetime of the oxygen radicals so that more of them will participate in Xing's anneal process.

5e. Given the cumulative effect of these teachings in the prior art, it would be understood by a person skilled in the art that the low end of the H₂/H₂+O₂ range in Wang '102 (namely about 0.1%) would not be expected to produce an exothermic flame at conventional pressures and thus is not recommended; whereas the more "usual" and preferable range of "5% to 33%" recited at Wang paragraph [0018] would be more likely to do so. And the ordinary artisan would conventionally want to ignite a hydrogen flame at the surface undergoing oxidation for at least the reasons given above.

5f. Wang '102 does not suggest his process as a means for reducing Bird's Beak, but rather as a means for reducing oxidation thickness disparity when oxide and nitride are being simultaneously oxidized. Thickness disparity is not at all the same thing as Bird's Beak. Thus, after having read Wang '102, a person of ordinary skill would not see any relation between what Wang '102 teaches and the problem of reducing Bird's Beak.

5g. Bird's Beak does not occur from the fact that SiN and Si are being simultaneously oxidized. It occurs because oxygen permeates laterally and rapidly through a relatively porous

layer of oxide that is situated immediately adjacent to a silicon layer and the oxygen is thus able to attack the adjacent silicon layer and oxidize it.

5h. It is noted Wang has an exposed edge of his TOX layer 424 in Fig. 4E but no overlying polysilicon. Layer 426/427 is nitride. Bulging oxide growth 434 indicates volume enlargement as silicon implant region 432 and substrate are thermally oxidized. Wang provides no suggestion that a relatively dry ISSG might reduce lateral advancement of an oxidation front due to reduced lifespan of oxygen radicals and that this may in turn provide a useful solution to the long known and not fully solved, Bird's Beak problem. It seems to me that the Patent Office is copying the idea of using dry ISSG for Birds' Beak out of the subject patent application and then projecting it by way of hindsight into Wang '102 at the portion of OA page 3 where they mention Xing '873 as evidence of the state of the art.

5i. However, my review of Xing '873 shows no place where Xing suggests that the relatively short lifetime of oxygen radicals may be usefully applied to the problem of Bird's Beak. Quite the opposite. At paragraph [0025] Xing '873 teaches that the relatively short lifetime of oxygen radicals is a problem to be overcome by using low pressure so that more, not less, oxygen radicals will penetrate into the region undergoing his anneal process. The goal in Xing '873 is, of course, to increase the number of oxygen bonds per steps 204 and 210 of his Fig. 2. The ISSG process is used in Xing '873 only to enhance oxidation through the top major surfaces of oxide layers 408 and 412 of his ONO structure 414 (see Fig. 4E). This is evidenced by paragraph [0037] of Xing '873 wherein the stack is not lithographically patterned and etched until after all the ISSG operations have been performed. Thus Xing '873 teaches to perform ISSG only before the ONO stack is lithographically patterned and etched. This guides away from the teachings of You '613 wherein "dry" oxidation is performed after a metal silicide layer has been formed and after the stack has been etched. (As a subtle aside,

note that the tunnel oxide 404 of Xing Fig. 4B is not exposed to hydrogen incursion from the ISSG anneal (step 204) because the edge of TOX layer 404 is first sealed by an HTO oxidation step (202) that forms the bulk of first oxide layer 408.)

5j. Paragraph [0037] of Xing '873 teaches that "standard processing technique[s]" are to be used to complete fabrication. The ordinary artisan would interpret this to include the conventional, silane-base HTO oxidation of the stack sidewalls. The subject patent application explains at specification paragraph [0041] why the conventional sidewall oxidation process is an HTO one that uses DCS (or silane), as follows:

[0041] ... the conventional, sidewall oxidizing process is HTO (High Temperature Oxidation) as is schematically indicated at 120. One particular HTO process flows **DCS (dichlorosilane) and nitrous oxide (N₂O)** over the exposed ONO memory cell stacks 110 (only one shown) in order to trigger an exothermic reaction which releases molecular oxidizing agents (e.g., O₂) along the exposed sidewalls of the ONO towers 110. The DCS plus N₂O reaction simultaneously decomposes the DCS to provide silicon atoms for deposition and oxidation along the tower sidewalls. An encasing silicon oxide layer (not shown, see instead 250 of Fig. 2A) is quickly formed. Such quick formation is conventionally desired because the rapidity of the sidewall dielectric formation helps to **reduce fabrication costs for mass produced devices. It also helps in minimizing thermal budget problems.** ... *[Emphasis added.]*

5k. The ordinary artisan would agree that the emphasis is on having a reliable and consistent method for use in mass production for assuredly maintaining an exothermic reaction that releases heat in situ at the desired location (at the sidewall of the ONO structure). This is why DCS and N₂O are used as the method of choice in the industry; because they deliver almost all of the desirable attributes; except of course, that of preventing Bird's Beak (see the rest of paragraph [0041] in the specification).

51. The ordinary artisan would also know and agree with the proposition in the specification that an H_2/O_2 volumetric flow ratio of below a normal range (more specifically, below 0.3) is not to be used for generating exothermic heat in ISSG because the hydrogen flame may become unstable or nonexistent at lower values of the ratio and then the desired exothermic reaction may fail to consistently take place if at all. Some patent applications such as Wang 2005/0110102 may recite wide ranges of values for the H_2/O_2 mixture. However, the ordinary artisan would know to discount the extremes of these ranges as being mere puffery and not truly a workable or "usual" range to operate in. There would be no advantage to operating in the questionable extremes (in so far as one not knowing of the present invention is concerned) and there would be all the risk of losing the exothermic flame and then losing the advantage of in-situ heat generation and of process consistency. Any isolated document can recite wide and unrealistic ranges. That does not mean that a person of ordinary skill will blindly accept the ranges of a single document as being credible. Instead, the ordinary artisan would, like any reasonable person with appropriate training, seek to discover what the mainstream of teachings in the art relate to him and would follow that mainstream of conventional guidance. In the present situation, the subject patent application correctly indicates that the mainstream thinking prior to the critical date was to keep the volumetric flow ratio of H_2/O_2 (each in terms of sccm) in an ISSG process in a range above 1.0 (above unity) or at least above 0.3 given that the flame is known to become unstable or extinguished below such levels (i.e., below 0.3). (Note that an H_2/O_2 ratio of 0.3 becomes an $H_2/(O_2 + H_2)$ ratio of about 0.23; or more generally that an H_2/O_2 ratio of x becomes an $H_2/(O_2 + H_2)$ ratio of $x/(1+x)$ so that, as x approaches unity, the value of $x/(1+x)$ approaches 50%.)

5m. With regard to supplementing a dry ISSG step with a DCS HTO step, certainly the ordinary artisan would not have known of the idea related at paragraphs [0055]-[0056] of the subject patent application, namely, to supplement the dry ISSG with a DCS HTO. The reason for going through the complication of performing a dry ISSG and then a conventional HTO is to gain benefit of the unexpected result that short-lived oxygen does not permeate deep into the stack during the dry ISSG. At OA page 3 (where the reference to Xing '873 is made), the Final Office Action appears to imply that the ordinary artisan would have seen the connection between the normally short lifetimes of oxygen radicals (as may occur for example during ISSG) and the problem of Bird's Beak. I have carefully reviewed You '613, Wang '102 and Xing '873 looking for a place where any of these references might provide a hint of such a connection and I have found none. In my professional opinion, a person of ordinary skill in the art could not have seen such a connection. The connection (as disclosed only in the subject patent application) and the desirable results of reduced Bird's Beak are a surprise.

5n. At this point I am probably straying dangerously close to opining on the legal concept of "nonobviousness". So I stop here and summarize my conclusions as follows.

6. Summary

6a. It is my opinion that the Final Office action of June 6, 2006 for the subject patent application contains numerous errors of fact finding as detailed above and it does not present to me a convincing prima facie, factual case of unpatentability based on the prior art that is cited. You '613 does not teach or suggest to the ordinary artisan that the "dry" oxidation of his nitride-coated ONO stack should be replaced by a hydrogen-containing oxidation of an uncoated (exposed) ONO stack. The covering of You '613's ONO stack with a nitride coating prior to performance of the "dry" oxidation is a vital part of what You '613 teaches. A person of ordinary skill would not have been guided or motivated by You '613 to do something different, especially to leave the stack "exposed" and to use a hydrogen-containing atmosphere for generating sidewall oxide.

6b. Wang '102 does not teach or suggest to the ordinary artisan that ISSG should be used in place of another oxidation process (i.e., dry oxidation) in any and every situation. Wang '102 is limited to the situation where it is just oxide and nitride that are to be simultaneously exposed to an oxidizing environment and it is desirable to reduce oxidation thickness disparity. Wang '102 cannot be logically combined with You '613 because You has a metal silicide layer.

6c. Xing '873 guides the ordinary artisan toward assuring that a large number of long-lived oxygen radicals should be generated at the surface that is undergoing ISSG oxidation and that sufficient hydrogen be present to assure ignition of the hydrogen flame.

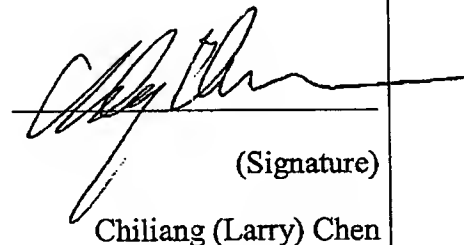
6d. Prior to the critical date, a person of ordinary skill in the art could not have reasonably seen a logical connection between the disparate teachings of You '613, Wang '102 and Xing '873 that would motivate the artisan to combine two or more of these teachings

together. None of these prior art documents provide a suggestion that short-lived oxygen radicals might result in reduced Bird's Beak formation. Of course, with hindsight and after-the-fact knowledge of the successful experiments performed by the present inventors (see experimental results of Figs. 4A-4C of the subject patent application) one can then see the connection and surmise as to the probable cause and effect. However, before that, the connection between Bird's Beak and short-lived radicals was not seen. It was a surprise revelation.

6e. I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true, and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under §1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

Signed this 1st day of November in the year 2006

at Santa Clara, California.


(Signature)
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